Standardization of Light Intensities for Different Indoor Ornamental Plant Species in an Indoor Vertical Garden

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Abstract

The present study was conducted to investigate the light intensity requirements for the optimal growth of indoor ornamental plants suitable for vertical gardening under Indian conditions. Five ornamental plant species—*Philodendron selloum*, *Syngonium podophyllum*, *Schefflera arboricola*, *Dracaena godseffiana*, and *Scindapsus aureus*—were grown in pots containing a growing medium composed of cocopeat, perlite, and vermiculite. These pots were arranged on vertical structures aligned with the interior walls of a room. Four experimental frames, including one control, were established under LED lighting with varying light intensities. LED lights of varying intensities were controlled using Pulse Width Modulation (PWM). The levels of light intensity were 700-1100 lux, 1100-1500 lux, 1500-1900 lux, and a control group of 150-250 lux without artificial lighting. The experiment was laid out according to a Factorial Completely Randomised Design (CRD). SAS software was used for the statistical analysis of the data obtained from the experiment. Duncan's Multiple Range Test (DMRT) was used to compare the means of the treatment groups at a 5% level of significance. The results of the experiment showed that *Philodendron selloum* species grew best under light intensity I (700-1100 lux), *Dracaena godseffiana* species grew best under light intensity II (1100-1500 lux), *Syngonium podophyllum* and *Schefflera arboricola* species exhibited the best growth under light intensity III (1500-1900 lux). *Scindapsus aureus* grew well under light intensity I and II. The findings of this research project provide valuable information regarding the lighting requirements of specific plant species which can inform the planning and management of indoor vertical gardens in India.

Keywords: LED Light intensities, Indoor vertical garden, Indoor ornamental plant species, Hoagland's solution, Plant leaf nutrient analysis, Growth, physiological, biochemical parameters

1. Introduction

This era of modernization and urbanization, has led to an increase in human population around the world as well as in India which is putting tremendous pressure on natural resources especially on land and water. There is also a demographic shift of the rural population to urban and semi-urban areas and nearly 80% of the population will

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become urban as compared to 50 % as of on today (Arumugam and Tamilselvi, 2018). This has created new challenges in the environment such as an ever-shrinking supply of dynamic resources, climate change and a deeply unbalanced ecosystem. People in the cities are devoid and often complain about lack of greenery, fresh air, lack of biodiversity etc. Especially, for a developing country like India, where the metropolitan cities are full of skyscrapers, which has led to building up of concrete jungles and lack of green areas. The configuration of urban areas has an impact on the local microclimate, which in turn influences the energy consumption of buildings (Chiang and Tan, 2009). This relationship is crucial in the pursuit of developing cities that are sustainable and can effectively mitigate the effects of climate change (Saffuan et al., 2013). Replacement of vegetation/green spaces with concrete ones in the urban areas have increased the temperature by 6 °C than in rural areas because of the ability of concrete surfaces to absorb, retain and reradiate more solar energy than vegetation (Jain and Janakiram 2016). There is a great need of providing lungs of green space for these concrete jungles. As we humans are moving farther away from nature, this also makes it necessary to provide urban population with living green places so as to inculcate a sense of belonging and closeness to mother earth. Need is the mother of innovations and development. People are adopting urban landscaping as they are becoming more conscious about a cleaner and greener environment. Implementation of new technologies such as vertical gardening is an important step in this direction as there is little space for gardening available horizontally. Introduction of this concept in cities will have a big and positive environmental effect and is the right solution for saving environment at different places. Moreover, it can also be beneficial in generating added employment opportunities and crafting a healthy urban environment which will not only improve the wellbeing and performance but also the work productivity of the people.

Indoor ornamental plants, specifically foliage plants, are primarily focused on their vegetative growth and physical characteristics. Among the various environmental factors that affect plants, light is a complex and variable factor that has a vital function in photosynthesis development and growth. The light requirements of indoor ornamental plants vary depending on the species. While indoor plants generally require less light than outdoor plants, there are minimal and ultimate levels of light intensity that are required for the plants to grow and develop properly. Due to the potential lack of light levels required by the indoor foliage plants, it is important to optimize the levels of light that are emitted by the indoor vertical gardens. LEDs are one type of lighting that can be utilized for these indoor vertical gardens. LED lights are compact in size, last longer than other types of bulbs, are eco-friendly, and emit light of a single wavelength. Furthermore, LEDs have been proven to be effective for use as energy-efficient indicator lamps. The bulbs emit bright light over a wide viewing angle. The compact size of these lights, the fact that they emit light of a single wavelength, the solid-state structure of the bulbs, and the lifespan of LEDs as compared to other types of bulbs makes LEDs an ideal type of light for the vertical gardens to use for illumination of the indoor plants (Schuerger et al., 1997). As there is little information accessible on the optimum light intensity requirements for different indoor ornamental plant species to be grown in an indoor vertical garden, the study is crucial under Indian conditions. Scientific work related to this topic with proper scheme for installation and maintenance of plants in vertical landscape system in the Indian scenario, needs to be significantly increased. The examination was subsequently started to assess indoor plants and to standardize their light intensity requirements for a functional indoor vertical garden. The major objectives of this research can be summarized as follows:

- Analysing the best lighting conditions for the growth of indoor decorative plant species in a vertical indoor garden in India.
- Analysing the response patterns of five indoor attractive species of plants (*Schefflera arboricola, Dracaena godseffiana, Philodendron selloum, Syngonium podophyllum, and Scindapsis aureus*) to different light intensities with regard to of growth, physiological, biochemical, and leaf nutrition elements.
- Analysing how various light intensities affect the responses of various plant species and determining the range of light intensities that produce the most productive beneficial responses.
- Providing scientific data and recommendations regarding the suitable light intensity for each plant species in an indoor vertical garden setting.
- Addressing the lack of scientific information on light intensity requirements for indoor ornamental plants in vertical gardening, particularly in the context of Indian conditions.

By conducting this study and by achieving these objectives, it is aimed to contribute to the scientific knowledge and understanding of vertical gardening indoors, and in what light intensities the different indoor ornamental plant species should be provided for optimal growth.

Gautam et al. (2021) performed a study on indoor vertical gardens. Within their study, they discussed the importance of light to the growth of plants. Furthermore, they investigated the light intensity that was required to achieve ideal growth for five different varieties of indoor ornamental plants when grown indoors in India. These plants were arranged into vertical structures within the garden, and were provided with LED lighting of varying light intensities. Results from this study indicated that each of the different species of plants have a best light intensity for their growth, such as *Philodendron salloum*, *Scindapsis aureus* and other species. Pennisi et al. (2020) performed a study on the impact of different lighting on indoor plant gardens. Their goal was to determine the ideal light intensity for basil and lettuce plants when provided with only red and blue fluorescent lights. Results indicated that increasing the light intensity led to an increase in the biomass of the basil and lettuce plants, but only up to a certain level; beyond that level, no additional biomass was produced. Furthermore, water and energy efficiencies for the indoor gardens were found to be best at certain levels of light intensity. Matysiak et al. (2021) conducted study on the effects of various light intensities on romaine lettuce plants. Plants were grown in a deep water culture system, but were exposed to LED lights of various spectra. Results indicated that a spectrum of 70% red, 18% green, and 12% blue light best promoted leafy biomass production of the romaine lettuce plants, but prevented the plants from accumulating certain nutrients. Additionally, the levels of nutrients in the water of the deep water culture system dropped over time, as did the levels of nutrients within the lettuce plants, and there were indications of tip burn of the plants.

Orlando et al. (2022) performed an investigation into the impact that various spectra and levels of light can have upon the growth and healthy value of various micro greens. Lower light intensities had a negative impact upon the growth and phenolic contents of the micro green species. However, the inclusion of green light at higher intensities had some favourable consequences upon the phenolic contents and antioxidant activity of those species. Balliu et al. (2021) performed a review of the various soilless culture systems and how they can impact the root system of the plants grown within those cultures. Various factors that can impact the root system include factors like Root limitations, solution of nutrients, irrigation rate, rootzone temperature, oxygenation, and lighting are all factors to consider and more. Each of these factors can have an impact upon the growth of the plants cultivated in these systems. Finally, Baiyin et al. (2021) performed an investigation into the impact that flow rates of hydroponic culture solutions can have upon the growth of plants like Swiss chard. Too high flow rates can lead to inhibition of root growth and nutrient absorption by those plants.
Chen et al. (2022) performed a 12-month investigation into the effect that different lighting conditions can have upon the growth of the plant species Vallisneria natans. While the individual biomass and leaf attributes of the plant decreased with increasing light levels, the quantity and biomass of the plant's ramets increased. Additionally, Yuan et al. 2022 investigated the effect that the size of the tubers of the species Vallisneria spinulosa, the depth to which those tubers are buried, and the light intensity upon those plants can have upon their growth. Small tubers were shown to be more sensitive to alterations of those variables than large tubers, which naturally burrow shallowly into the ground and contain high levels of light. Finally, Spaninks et al. (2020) conducted a study into the effects that various forms of LED lighting, specifically red, blue, and white light, can have upon the vegetation of both *Arabidopsis thaliana* and *Solanum lycopersicum* (tomato) plants.
When exposed to LED light, tomato plants responded just somewhat, whereas Arabidopsis revealed major variations in growth, organ formation, and developmental transitions. The impact of LED lighting on the concentration of specialised metabolites in edible flowers, microgreens, and medicinal plants were discussed by Appolloni et al. in 2022. The majority of research used a red and blue light mixture with a 16-hour photoperiod and intensity above 200 mol m2 s1, which typically increased the level of specialised metabolites.

2. Methodology

The methodology workflow lay out for the research that focuses on establishing the light intensity necessities for indoor floral plant species in an indoor vertical garden according to Indian conditions is as outlined below:

2.1 Selection of plant species: Five indoor ornamental plant species were chosen for the study (see Figure 1), namely *Scindapsis aureus, Philodendron selloum, Dracaena godseffiana, Syngonium podophyllum, and Schefflera arboricola*. These species were selected based on their suitability for indoor vertical gardening.

Fig 1. Indoor ornamental plant species screened during experiment

2.2 Preparation of growing media: Figure 2 represented the growing media mixture consisting of cocopeat, perlite, and vermiculite in a ratio of 3:1:1 was prepared. This media provides a suitable substrate for plant growth and root development.

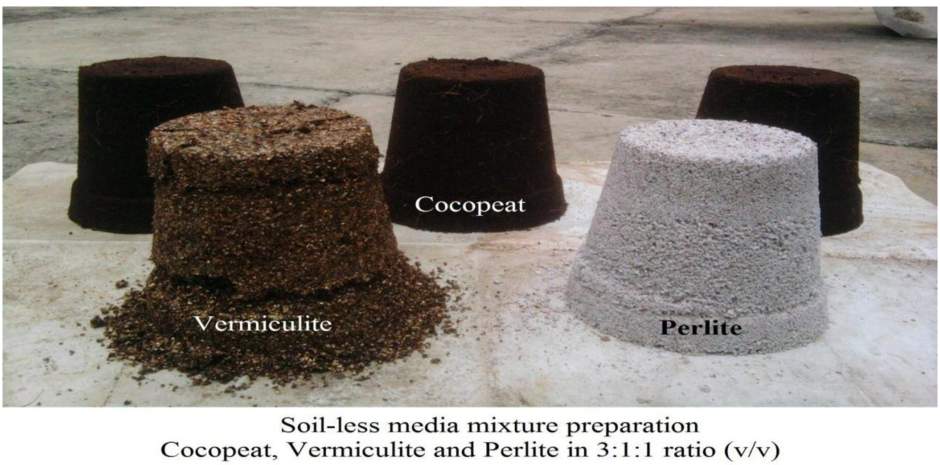

Fig 2. Soil-less media mixture preparation

- **Setup of vertical structures:** The plants were planted in 5" pots filled with the prepared growing media. These pots were then arranged as vertical structures measuring 6'11" x 4'3". The structures were aligned against the walls of an indoor room.
- **Fabrication of frames:** Four frames were fabricated for the experiment, including one control frame as shown in the Figure 3. Each frame represented a different light intensity treatment. The first frame was illuminated with light intensity ranging from 700-1100 lux (LI I), the second frame with 1100-1500 lux (LI II), the third frame with 1500-1900 lux (LI III), and the fourth frame served as the control with no artificial light illumination (150-250 lux).

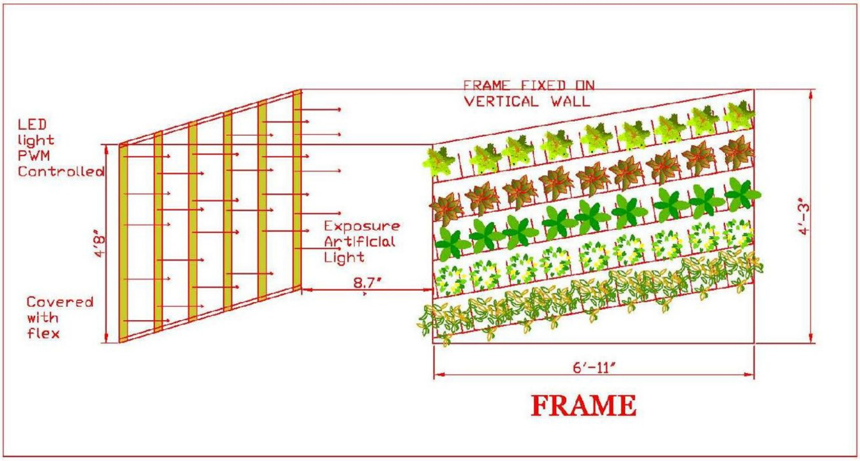

Fig 3. Layout of experiment depicting artificial illumination of the plants in the indoor vertical garden with LED lights created by vertical placement of the pots (5”) on the walls of the interiors of the room

- **Artificial light illumination:** LED lighting systems were used to provide the different light intensities to each frame. The light intensities were controlled using Pulse Width Modulation (PWM) techniques. This ensured accurate and controlled light intensity delivery to each frame.
- **Experimental design:** The experiment followed a Factorial Completely Randomized Design (CRD). The plant species were randomly assigned to each frame, and multiple replications were conducted to ensure statistical validity.
- **Fertilization and irrigation:** Standard fertilization and irrigation protocols were followed to provide optimal nutrient and water supply to the plants throughout the experiment. This ensured consistent growing conditions across all treatments.
- **Data collection:** Data were collected on various parameters to evaluate the plant's response to different light intensities. These included plant growth

parameters (e.g., total fresh and dry plant weight), physiological and biochemical parameters (e.g., photosynthetic rate, chlorophyll content), and plant leaf nutrient analysis (e.g., nitrogen, phosphorus, potassium content).

- **Data recording and analysis:** The collected data were recorded and organized for further analysis. Statistical analysis was performed using SAS software version 9.0. The interactions between different factors were compared using the Duncan Multiple Range Test (DMRT) at a significance level of 5%.
- **Evaluation of plant species' response:** The plant species' response to different light intensities was evaluated based on the most effective positive responses observed in terms of the various parameters studied. This analysis helped determine the optimal light intensity for each species in the context of indoor vertical gardening.

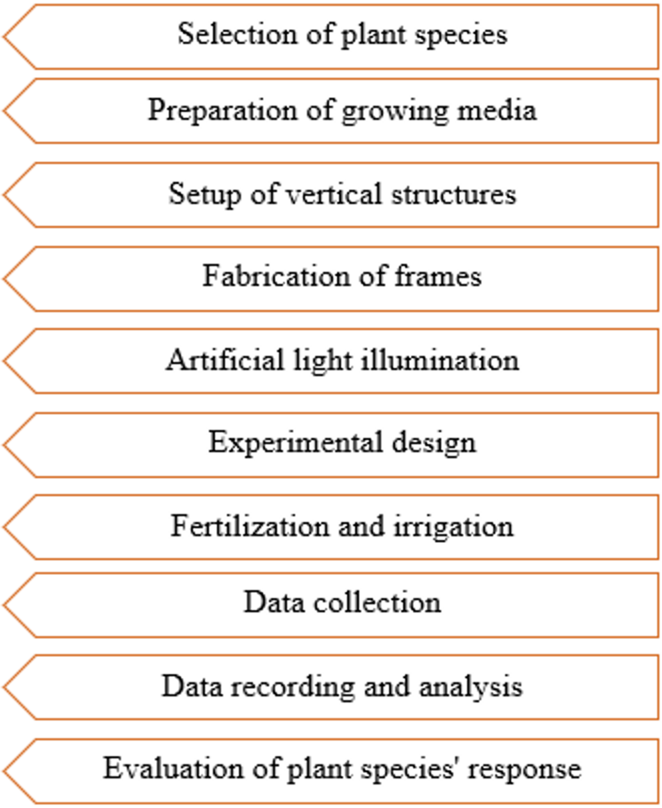

Fig 4. Workflow diagram

3. Experimental Setup

The experimental setup involved the construction of vertical structures measuring 6'11" x 4'3", which were aligned to the walls of an interior room. Within these structures, 5" pots were arranged to hold the plant material. The study focused on five specific indoor foliage species: *Dracaena godseffiana, Schefflera arboricola, Syngonium podophyllum and Philodendron selloum, and Scindapsis aureus*. The pots were filled with a growth media mixture consisting of cocopeat, vermiculite, and perlite in a ratio of 3:1:1. To provide artificial lighting, an LED lighting system with pulse width modulation (PWM) control was installed, allowing for different light intensities. Each vertical structure was given one of four separate light intensity ranges: I) 700–1100 lux, II) 1100–1500 lux, III) 1500–1900 lux, and IV) control (150–250 lux, corresponding to ambient room light). In order to ensure reliable results, three replications were created for each treatment, following a factorial completely randomized block design. This comprehensive experimental setup aimed to look into the effects of various light intensities on selected indoor ornamental plant species in a vertical garden setting. The flow chart

3.1 Fertilization and Irrigation

The fertilization and irrigation protocols were implemented to provide the necessary nutrients and water for the plants in the experiment. Fertigation, a combination of fertilization and irrigation, was carried out using the Hoagland's solution. The plants were fertigated with 100% of the Hoagland's solution, applying 100 ml per plant. This mixture of nutrients includes both macronutrients (like nitrogen, phosphorus, & potassium) and micronutrients (like calcium, magnesium, and sulphur) that are crucial for plant growth. Fertigation was performed every 10 days to ensure a regular supply of nutrients to the plants throughout the experimental period. In addition to fertigation, the plants were irrigated with plain water as needed. Irrigation with water alone was carried out approximately every 4-5 days, depending on the specific water requirements of the plants. This irrigation schedule aimed to maintain proper soil moisture levels and prevent water stress, ensuring optimal growth conditions for the plants. By combining fertigation with regular irrigation, the plants received a balanced nutrient supply along with sufficient water for their growth and development. This approach allowed for the controlled provision of essential nutrients and hydration, ensuring that the plants had the necessary resources to thrive in the indoor vertical garden environment.

3.2 Data Collection

1) Plant Growth Parameters

- Total fresh and dry plant weight: Dig out the entire plant, decontaminate, and measure the fresh weight using an electronic balance. Dry the samples at 60 ± 5 °C until a constant weight is attained.

2) Physiological and Biochemical Parameters

- Leaf chlorophyll content: Estimate using freshly removed and fully expanded leaves following the method described by Hiscox and Israelstam (1979) with Dimethyl sulfoxide (DMSO) as the extracting solvent.
- Measure the number of carotenes in newly removed, completely expanded leaves using the technique outlined by Kirk and Allen (1965).

- Relative leaf water content (RLWC): Weigh ten leaf discs from each treatment, saturate them in distilled water, and measure the fresh, saturated, and dry weights. Calculate RLWC utilising the formula provided.

$$\text{RLWC} = \left(\frac{Fresh\ weight - Dry\ weight}{Saturated\ weight - Dry\ weight}\right)100$$

- Proline: Determine leaf proline content using the method explained by Bates et al. (1973).

3) Plant Leaf Nutrient Analysis

- Leaf nitrogen: Estimate using the Microkjeldahl distillation method as per the A O A C ("Association of Official Analytical Chemists") 1970 standard.
- Phosphorus: Determine using the method given by Jackson (1973).
- Potassium: Measure using the Flame photometer method described by Jackson (1967).
- Calcium, magnesium, and sulfur: Estimate using an Atomic Absorption Spectrophotometer following the procedure outlined by Jackson (1967).

3.3 Data Recording and Analysis

Throughout the experiment, observations were made at regular intervals to examine different physiological, biochemical, and nutritional characteristics of the plants. Growth-related observations included estimation of total fresh biomass and dry biomass of the plants. Physiological assessments comprised of chlorophyll concentration, carotenoid pigments, and relative leaf water content (RLWC). In addition, biochemical evaluation involved measurement of proline deposition in the leaves. Leaf samples were further analysed to calculate the concentration of essential nutrients, namely nitrogen, phosphorus, potassium, calcium, magnesium, and sulphur. The recorded values for each parameter were expressed as mean values corresponding to the respective treatments and plant species under study. To determine whether the difference among the treatments were statistically meaningful, the acquired data were subjected to statistical estimation using software packages such as SAS (Statistical Analysis System). The analysis facilitated a better interpretation of the effect of varying light intensities on plant growth, physiological parameters and leaf nutrient absorption. Suitable statistical methods were applied to identify significant differences among the treatments.

4. Results and Discussion

4.1 Plant growth parameters:

The effect of different light intensities on plant growth and biomass accumulation was estimated in this experiment (Table 1). The results showed that an increase in light intensity significantly reduced the total fresh and dry weight of plants in *Schefflera arboricola*, *Dracaena godseffiana*, and *Syngonium podophyllum*. Conversely, *Philodendron selloum* showed improvement in biomass production under higher light intensities. For *Scindapsis aureus*, the highest fresh and dry plant weight was observed under LI II (1100–1500 lux), signifying that moderate light intensity was more suitable for its growth. Light intensity is widely identified as a major factor affecting plant growth and productivity as it directly influences the rate of photosynthesis and the synthesis of assimilates required for biomass formation. Earlier studies have also revealed that different plant species responds differently to varying light conditions, with each species having different optimum light requirements for healthy growth and development. The present findings are in agreement with previous reports describing species-specific responses to LED illumination and controlled indoor environments. Research has further revealed that certain ornamental species attain higher biomass production under moderate light levels rather than under excessively higher light intensities, as photosynthetic efficiency varies according to the physiological characteristics of each species. The differences observed among the studied plants clearly showed that plant response to light illumination is highly species dependent. While some species experienced a reduced growth rate with increase in light intensity, others performed best under medium or higher illumination levels. These findings propose that customized lighting management is crucial for successful indoor vertical gardening systems. Therefore, selecting suitable light intensities according to the individual requirements of each species is important to maximize plant growth, biomass accumulation, and overall performance of the plant.

Table 1. Response of plant species under study to different light intensities in terms of growth characteristics in an indoor vertical garden

Growth parameters	Indoor ornamental plant species	LI I 700-1100 lux	LI II 1100-1500 lux	LI III 1500-1900 lux	LI IV 150-250 lux (control)
Total fresh plant weight (g)	*Schefflera arboricola*	20.87c	28.77b	36.50a	0.00d
	Dracaena godseffiana	5.86c	7.75b	14.00a	0.81d
	Philodendron selloum	46.33a	40.90b	29.12c	0.00d
	Syngonium podophyllum	15.11c	30.42b	36.37a	3.49d
	Scindapsis aureus	15.41c	31.50a	18.22b	8.96d
Total dry plant	*Schefflera arboricola*	4.62c	6.77b	9.54a	0.00d
	Dracaena godseffiana	1.97c	2.33b	4.23a	0.36d

weight (g)	*Philodendron selloum*	9.52a	9.13b	3.77c	0.00d
	Syngonium podophyllum	5.98c	8.40b	11.11a	0.77d
	Scindapsis aureus	4.32b	8.22a	4.01b	0.68c

The different letters in each column are significantly different at $P \leq 0.05$ by Duncan's Multiple Range Test (DMRT)

4.2 Physiological and biochemical parameters

The effect of different light intensities on the physiological and biochemical behaviour of varying plant species grown in an indoor vertical garden is presented in Table 2. The results showed that leaf chlorophyll content reduced markedly in *Dracaena godseffiana*, *Philodendron selloum*, and *Scindapsis aureus* when exposed to the highest light intensity, LI III (1500–1900 lux), as compared to lower light intensities. This reduction may be correlated with the chlorophyll breakdown caused by excessive light exposure. Contrarily, *Schefflera arboricola* and *Syngonium podophyllum* attained highest chlorophyll concentration under LI III, indicating that this light range was optimum for chlorophyll synthesis for these species. Previous observations by Adamson et al. and Taiz and Zeiger revealed that shade-loving plants develop adaptive features like broader and thinner leaves along with a higher accumulation of chlorophyll content. The tendency of the plants to adjust to changing environmental conditions is closely linked with the formation and degradation of photosynthetic pigments. Chlorophyll synthesis usually occurs in the presence of light, but excessive illumination levels can accelerate photo-oxidative damage, thereby reducing total chlorophyll content, as observed by De Carvalho Gonçalves et al. Likewise, Li and Cheng also observed a significant rise in chlorophyll levels in cucumber seedlings grown under artificial LED light conditions.

Table 2. Response of plant species under study to different light intensities in terms of physiological and biochemical characteristics in an indoor vertical garden

Physiological and biochemical parameters	Indoor ornamental plant species	LI I 700-1100 lux	LI II 1100-1500 lux	LI III 1500-1900 lux	LI IV 150-250 lux (control)
Chlorophyll content	*Schefflera arboricola*	1.76c	2.27b	4.36a	0.06d

(mg/g fresh weight)	*Dracaena godseffiana*	6.95b	8.10a	3.98c	1.86b
	Philodendron selloum	4.34a	2.63b	1.27c	0.53d
	Syngonium podophyllum	1.04c	2.08b	2.87a	0.73b
	Scindapsis aureus	2.42a	2.20b	1.85c	1.08d
Carotenoid content (mg/g fresh wt.)	*Schefflera arboricola*	0.15c	0.25b	0.60a	0.05d
	Dracaena godseffiana	0.71b	0.81a	0.31c	0.18d
	Philodendron selloum	0.40a	0.19b	0.12c	0.04d
	Syngonium podophyllum	0.08c	0.23b	0.24a	0.03d
	Scindapsis aureus	0.27a	0.26a	0.20b	0.09c
Relative leaf water content (%)	*Schefflera arboricola*	79.75c	82.23b	84.40a	33.84d
	Dracaena godseffiana	79.70a	84.25a	80.92a	44.12b
	Philodendron selloum	83.68a	83.29b	82.04c	39.83b
	Syngonium podophyllum	77.85a	78.51a	80.75a	55.06b
	Scindapsis aureus	89.92a	88.07b	86.59c	82.95d
Proline content (mg/g dry wt.)	*Schefflera arboricola*	0.22b	0.16b	0.09b	1.71a
	Dracaena godseffiana	0.26a	0.13b	0.13b	0.23a
	Philodendron selloum	0.24a	0.28a	0.33a	0.18a
	Syngonium podophyllum	0.23a	0.07b	0.05b	0.20a
	Scindapsis aureus	0.06c	0.22b	0.22b	0.27a

A sequential increase in mean leaf carotenoid content was observed with increasing light intensities in *Syngonium podophyllum* and *Schefflera arboricola*, with the highest accumulation observed under LI III. In *Dracaena godseffiana*, the highest carotenoid content was observed under LI II. On the other hand, higher light intensities adversely affected carotenoid accumulation in *Philodendron selloum* and *Scindapsis aureus*. Photosynthetic pigments are vital components involving plant metabolic activities and overall growth of the plants. The present findings vary from those reported by Li and Cheng (2015), who observed insignificant influence of LED illumination on the carotenoid levels in cucumber seedlings. The substantial variations in carotenoid concentration observed among the various species examined in the current study under different light intensities may be attributed to species-specific variations in pigment accumulation when exposed to varying light conditions.

Relative Leaf Water Content (RLWC) measures the amount of water that a plant's leaves can hold. Leaf water status is closely associated with several leaf physiological variables such as growth, leaf turgor, transpiration, photosynthesis and respiration (Kramer & Boyer 1995). *Schefflera arboricola* showed a considerable rise in the mean RLWC with light intensities getting bigger, with optimum concentration at LI III (84.40%). The mean RLWC for the various light treatments applied to *Dracaena godseffiana* and *Syngonium podophyllum* did not differ statistically significantly. A significant decrease in the mean RLWC with increasing light intensity was observed in *Philodendron selloum* and *Scindapsis aureus.* Guo and Pan (2016) reported that different light intensities had significant effect on relative leaf water content of the plant. The variation in the results might be due to difference in the response to light intensities by different plant species.

Maximum proline content in case of all the species was seen to accumulate under control i.e. when the plants were not exposed to any artificial light. LI I (700-1100 lux) and LI IV (control) showed maximum accumulation of proline content in *Syngonium podophyllum* and *Dracaena godseffiana* whereas *Scindapsis aureus and Schefflera arboricola* under LI IV. *Philodendron selloum* showed insignificant effect when exposed to different light intensities. Optimum light is a perquisite for carrying out photosynthesis in plants. Lack of optimum light intensity may have led to stress conditions in the species under study as they become unable to carry out vital physiological processes which causes plants to accumulate an array of metabolites, especially amino acids. In the metabolism and growth of plants, amino acids are crucial. Proline accumulation and plant stress appear to be positively correlated, according to a number of studies. Proline is one such example and being an amino acid, it aids the plants in overcoming such stress conditions. This might be the reason of higher accumulation of proline content in the control plants (devoid of any artificial light intensity).

4.3 Plant leaf N, P and K content

The influence of varying light intensities on leaf nutrient composition (N, P and K) in various plant species grown under an indoor vertical gardening system is depicted in Table 3. The findings revealed that increased light intensities i.e. from LI I to LI III caused a noticeable decrease in leaf nitrogen, phosphorus and potassium content in

Philodendron selloum and *Scindapsis aureus*. In contrast, *Schefflera arboricola* showed an opposite trend, with improved nutrient accumulation under higher light intensities. Nitrogen plays a critical role in maintaining proper plant growth and physiological development. Similar observations were reported by Li and Cheng, who noted improved nitrogen accumulation in cucumber seedlings supplied with artificial LED illumination along with Hoagland's nutrient solution. Their study also confirmed noticeable differences in phosphorus and potassium contents under different light conditions. Earlier, Gulmon and Chu documented reduced leaf nitrogen content at reduced light levels, which are in agreement with the pattern observed in *Schefflera arboricola* in our study. However, *Philodendron selloum* and *Scindapsis aureus* accumulated comparatively higher nitrogen content under lower light intensity, suggesting that such light conditions may be more favourable for nutrient uptake and growth in these species. According to Evans, accumulation of nitrogen in plants is highly influenced by the amount of light intensity received.

Table 3. Effect of different light intensities on the leaf N, P and K content (%) of the indoor plant species grown in an indoor vertical garden

Plant leaf nutrient analysis	Indoor ornamental plant species	LI I 700-1100 lux	LI II 1100-1500 lux	LI III 1500-1900 lux	LI IV 150-250 lux (control)
Nitrogen (%)	*Schefflera arboricola*	2.49c	2.55b	2.60a	1.18d
	Dracaena godseffiana	2.24a	2.30a	2.28a	1.29b
	Philodendron selloum	3.61a	2.76b	2.60b	1.28c
	Syngonium podophyllum	3.10ab	3.57a	3.79a	2.12bb
	Scindapsis aureus	2.72a	2.45b	2.40c	2.46b
Phosphorus (%)	*Schefflera arboricola*	0.22c	0.41b	0.47a	0.06d
	Dracaena godseffiana	0.25b	0.38a	0.23b	0.09c
	Philodendron selloum	0.40a	0.31b	0.26c	0.11b
	Syngonium podophyllum	0.46a	0.54a	0.56a	0.23b
	Scindapsis aureus	0.55a	0.46b	0.43c	0.39d

Potassium (%)	*Schefflera arboricola*	2.14c	2.42b	2.68a	1.03d
	Dracaena godseffiana	2.70b	3.69a	2.55b	1.28c
	Philodendron selloum	3.99a	2.94b	2.37c	1.05d
	Syngonium podophyllum	3.23a	3.60a	3.50a	1.94b
	Scindapsis aureus	3.55a	3.21b	3.08c	2.47d

Higher phosphorus accumulation at optimum light intensities might have resulted in better root growth of the indoor plant species under experimentation which resulted in better nutrient uptake and ultimately produced healthy growth of the plants. Insignificant effect of different light intensities on leaf N content in *Dracaena* godseffiana and N, P & K content in *Syngonium podophyllum* was observed. The results obtained in our study are in agreement to the studies conducted by Kang and Iersel (2002) in ornamental bedding plants which suggested that nutrient accumulation in plants is totally species dependent.

4.4 Plant leaf Ca, Mg and S content:

The results of various light intensities on a leaf (Ca, Mg and S content) of the plant species grown in an indoor vertical garden has been shown in Table 4. A significant decrease in the percent leaf Ca, Mg and S concentration with increase in light intensities was observed in *Philodendron* selloum and Scindapsis *aureus,* whereas reverse was true for *Schefflera arboricola.* Insignificant difference in terms of leaf Ca, Mg and S content was observed in *Dracaena godseffiana* and *Syngonium podophyllum*. Also, insignificant results in the leaf sulphur accumulation was observed in *Syngonium podophyllum* and *Philodendron selloum.*

Table 4. Effect of different light intensities on the leaf Ca, Mg and S content (%) of the indoor plant species grown in an indoor vertical garden.

Plant leaf nutrient analysis	Indoor ornamental plant species	LI I 700-1100 lux	LI II 1100-1500 lux	LI III 1500-1900 lux	LI IV 150-250 lux (control)
Calcium (%)	*Schefflera arboricola*	1.17c	1.30b	1.41a	0.56d
	Dracaena godseffiana	1.12a	1.31a	1.30a	0.54b
	Philodendron selloum	1.31a	1.11b	1.00b	0.43c

	Syngonium podophyllum	1.31a	1.32a	1.34a	0.86b
	Scindapsis aureus	4.64a	3.91b	2.72c	3.02c
Magnesium (%)	*Schefflera arboricola*	0.63b	0.64b	0.67a	0.28c
	Dracaena godseffiana	0.13a	0.14a	0.14a	0.08b
	Philodendron selloum	0.79a	0.69b	0.56c	0.28d
	Syngonium podophyllum	0.36ab	0.42ab	0.47a	0.26b
	Scindapsis aureus	0.46a	0.37b	0.34c	0.30d
Sulphur (%)	*Schefflera arboricola*	0.16a	0.17a	0.17a	0.08b
	Dracaena godseffiana	0.23a	0.23a	0.23a	0.15b
	Philodendron selloum	0.40a	0.31b	0.25c	0.13b
	Syngonium podophyllum	0.27ab	0.31a	0.36a	0.18b
	Scindapsis aureus	0.22a	0.19b	0.15c	0.15c

Various studies have revealed ion antagonistic effects among Ca and Mg, that have resulted in nutrient accumulation differences in vegetation (Ohno and Grunes 1985; Ding et al. 2006). Ca and N works synergistically in enhancing plant growth (Karimi et al. 2012). Light intensity at which maximum N and Ca concentration has been accumulated can be termed as optimum as the plant shows good growth at these concentrations. Similar response was observed in our study which is evident as there was a proportionate increase in N and Ca content in the leaves under different light intensities. Percent leaf Mg content also varied at different light intensities for different species under experimentation. Higher content of Mg accumulated in the leaves of the indoor plant species resulted in better accumulation of pigments as Mg forms a key element in chlorophyll synthesis.

5 Conclusion

In conclusion, our research findings demonstrate that providing indoor ornamental plant species with 100% Hoagland's solution in combination with LED lighting at different light intensities can stimulate plant growth, enhance physiological and biochemical traits, and improve leaf nutrient characteristics. However, the optimal light intensity for each plant species varied. Based on the findings, it can be said that *Dracaena godseffiana* responded most favourably to LI II (1100–1500 lux), while *Philodendron selloum* gave best response to LI I (700–1100 lux). The strongest responses from *Syngonium podophyllum* and *Schefflera arboricol*a were seen at LI III (1500–1900 lux), whereas *Scindapsis aureus* responded well to both LI I and LI II. The above results emphasise the significance of considering the specific light intensity requirements of different indoor ornamental plant species to optimize their growth and overall performance. Understanding the preferred light intensities for each species can inform the design and management of indoor vertical gardens, enabling growers to provide the most suitable light conditions for maximum plant productivity and aesthetic appeal. It is essential to note that our research includes to the current pool of knowledge on indoor plant growth under LED lighting and highlights the species-specific nature of plant responses to light intensity. Further studies focusing on a wider range of plant species and different environmental conditions will provide more comprehensive insights into the standardization of light intensities for indoor ornamental plants in vertical gardens.

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Declaration of interest

The contributors affirm that they do not have any prior competing business interests or professional connections that might appear to have influenced the work presented in this paper.

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